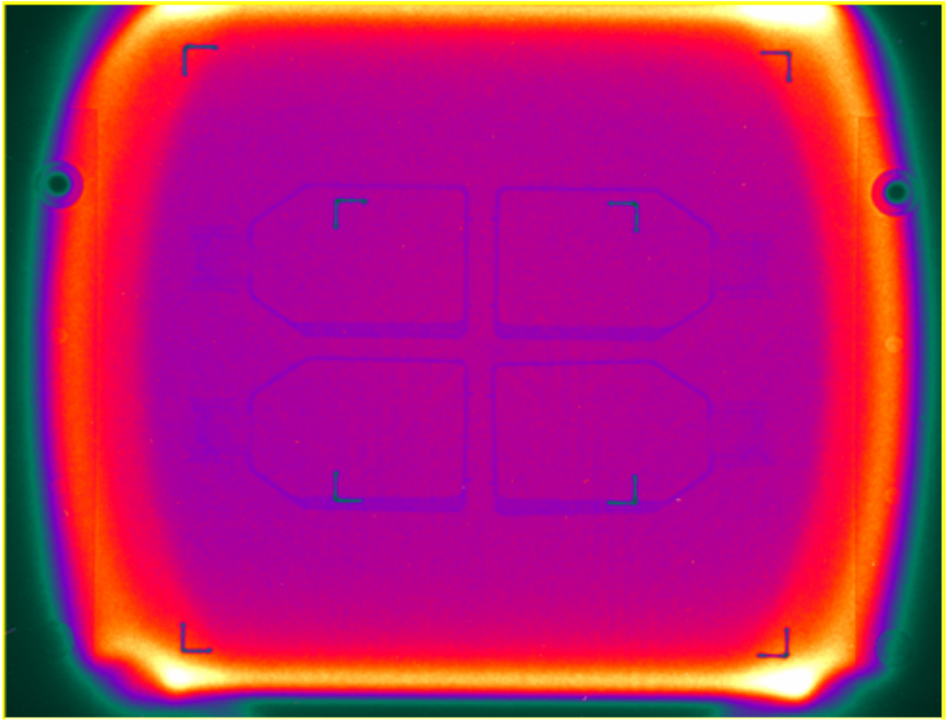
Using NSRL as a Test Beam



Transformative Hadron Beamlines
21 July 2014
Michael Sivertz

Philosophy

NSRL was designed by NASA with radiobiology in mind.

It is a User Facility, intended to make running experiments easy.

Users have a great deal of control over the operation of their experiments, along with a dedicated support staff.

- Changing beam conditions (shape, flux, target) can be accomplished in seconds.
- Changing beam energy can be done in minutes.
- Changing ion species can be done quickly.

Beam flux is tailored for radiobiology: ~1 Gray/minute (100 Rads/minute).

This corresponds to ~$3x10^9$ protons per cm^2 per minute,

or $4x10^6$ Fe ions per cm^2 per minute.

Beam spot is shaped magnetically to produce a large ($20x20cm^2$) flat field.

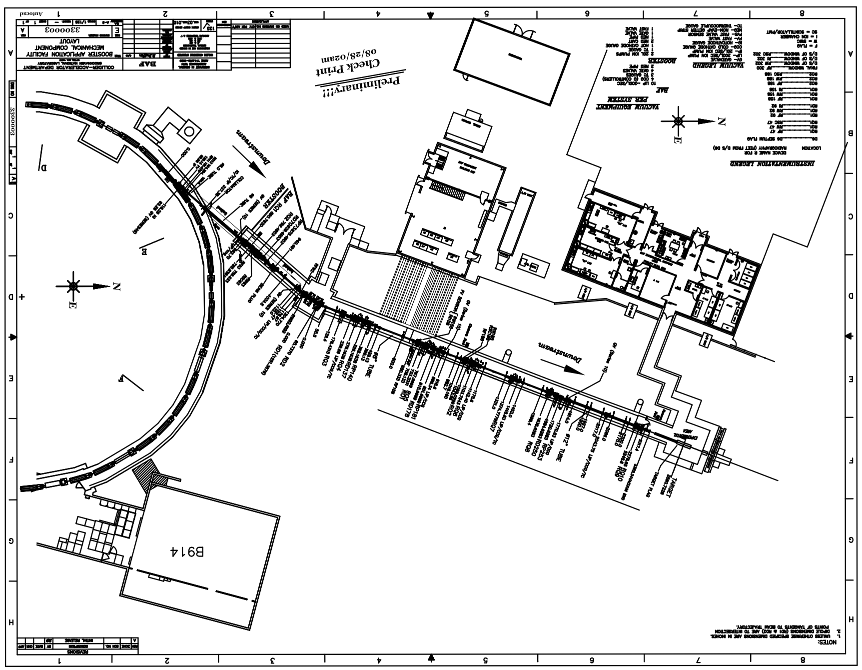
Exposures take ~1 minute, target changes take ~5 minutes. Access is quick and easy, compared to RHIC/AGS experience.

Philosophy (continued)

NSRL operates for the NASA Radiobiology program for 6 months a year. During those months, there is little to no chance for non-NASA users to gain access to the facility.

It could be possible to fit in a short beam test of a few hours up to a day after hours or on weekends during the NASA program, but longer experiments would need extensive coordination.

NSRL Beamline Design



NSRL Beamline designed to be achromatic with a series of 9 quads, 10 steering/pitching dipoles, and a pair of octupoles to produce a large bowl-shaped intensity distribution suitable for radiobiology experiments.

What NSRL can do!

- Projectile Options:
  - Protons
  - Heavy Ions (Helium through Gold so far…)
- Beam Energy
  - 50 – 2500 MeV for protons.
  - 50 – 1000 MeV/n for heavy ions up to Z=26 (Iron).
  - Reduced peak energy for ions heavier than Iron, to 165 MeV/n for Gold.
  - Stopping beam
- Flux
  - From 10 protons per spill to 10^{12} protons per spill.
  - From 10 to $2x10^{9}$ Fe-ions per spill.
- Shape
  - Large uniform square beam spot, up to 60 x 60 cm^{2}
  - As small as 1 cm spot size, uncollimated.

What NSRL cannot do!

- Projectile Options:
  - Electrons (positron, muons, neutrinos…).
  - Secondary particle beams (π, K, …).
- Beam Energy
  - No high energy beams possible, although we are looking into upgrading the peak energy by 50%.
- Flux
  - No death ray beams, limited by radiation safety envelop.
- Shape
  - No microbeams. It is hard to collimate 1 GeV protons, or even Fe beams.
- Momentum analyzed final states
  - No magnets in the target room.
  - No tracking chambers.

Ions, Energies, and Flux

This is what NSRL has already done. Much more is possible, but it has not yet been requested by users.

Ion species	**^{1}H**	**^{2}He**	**^{12}C**	**^{16}O**	**^{20}Ne**	**^{28}Si**	**^{35}Cl**	**^{40}Ar**	**^{48}Ti**	**^{56}Fe**	**^{84}Kr**	**^{131}Xe**	**^{181}Ta**	**^{197}Au**
Kinetic Energy (MeV/n) - Max - Min	2500 <50	1000 <50	1000 65	1000 <50	1000 70	1000 93	1000 500	350	1000 150	1000 <50	383	228	313 292	165 76
Flux (ions/spill x10^{10}) - Max	64	0.88	1.2	0.4	0.10	0.30	0.20	0.02	0.08	0.20	2E7	5E7	3E8	1E8
LET Range (keV/μ) in water.	0.21 - 1.26	0.89 - 5.01	8.01 - 36.8	14.2 - 80.5	22.2 - 96.4	44.0 - 151	64.0 - 80	106	108 - 265	150 - 832	403	1204	1827 - 1896	3066 - 4828

Momentum dispersion is given approximately by $dp/p \approx 0.005$

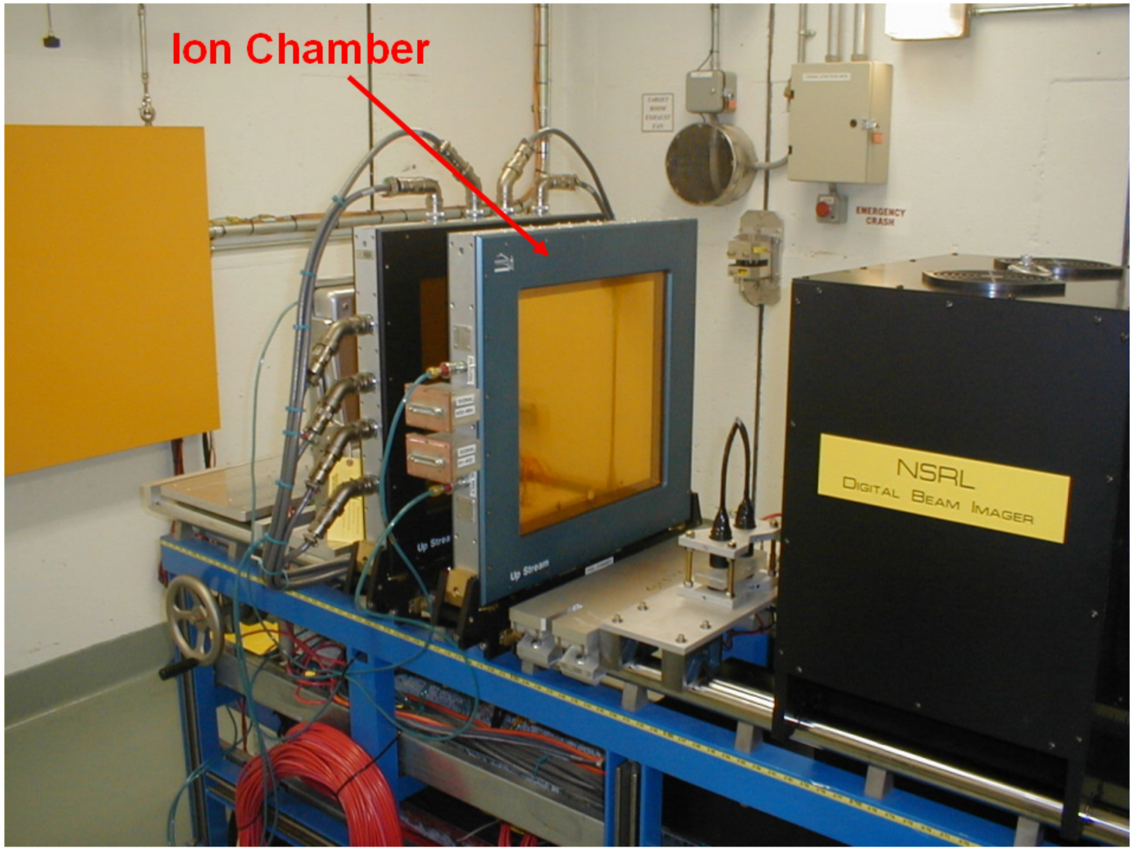
21 July 2014

Beam Monitoring

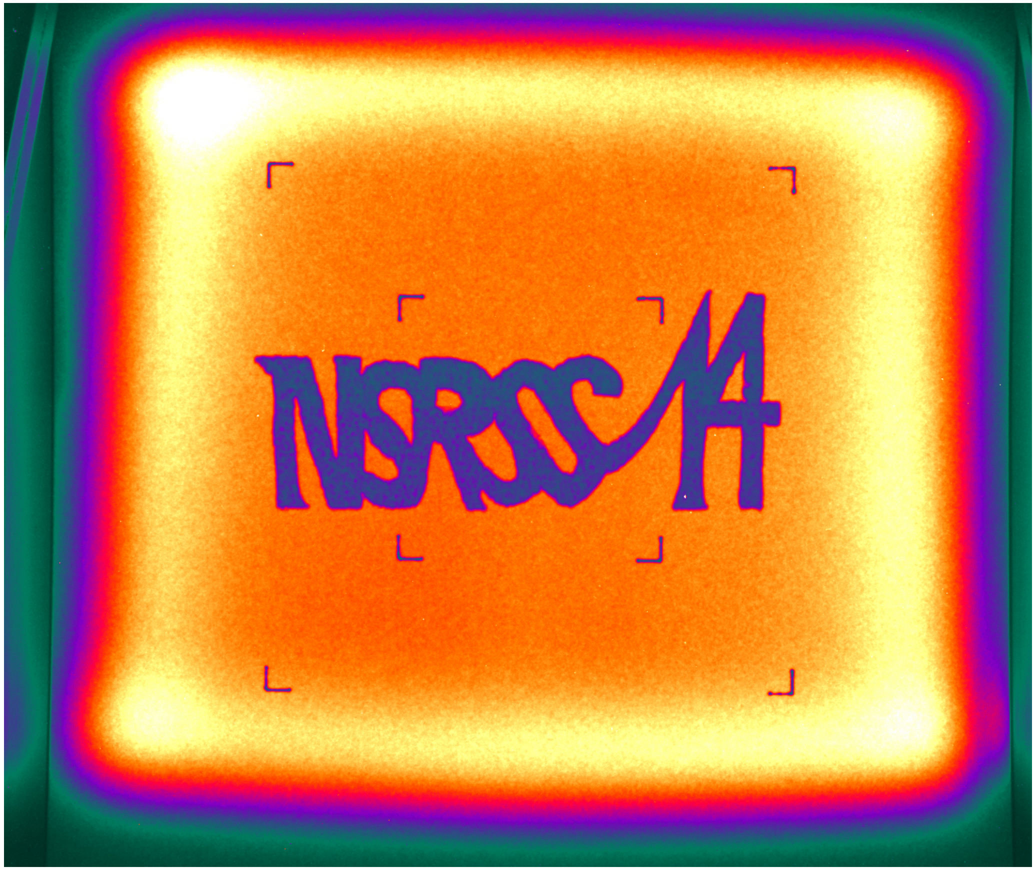
High flux exposures make use of a large planar ion chamber to measure and cut-off the beam delivery.

Low flux exposures use a 1 cm^2 plastic scintillator (or scintillator pair in coincidence for proton beam running) to measure and cut-off beam.

Beam Camera gives real time information on beam status.



Beam Shape



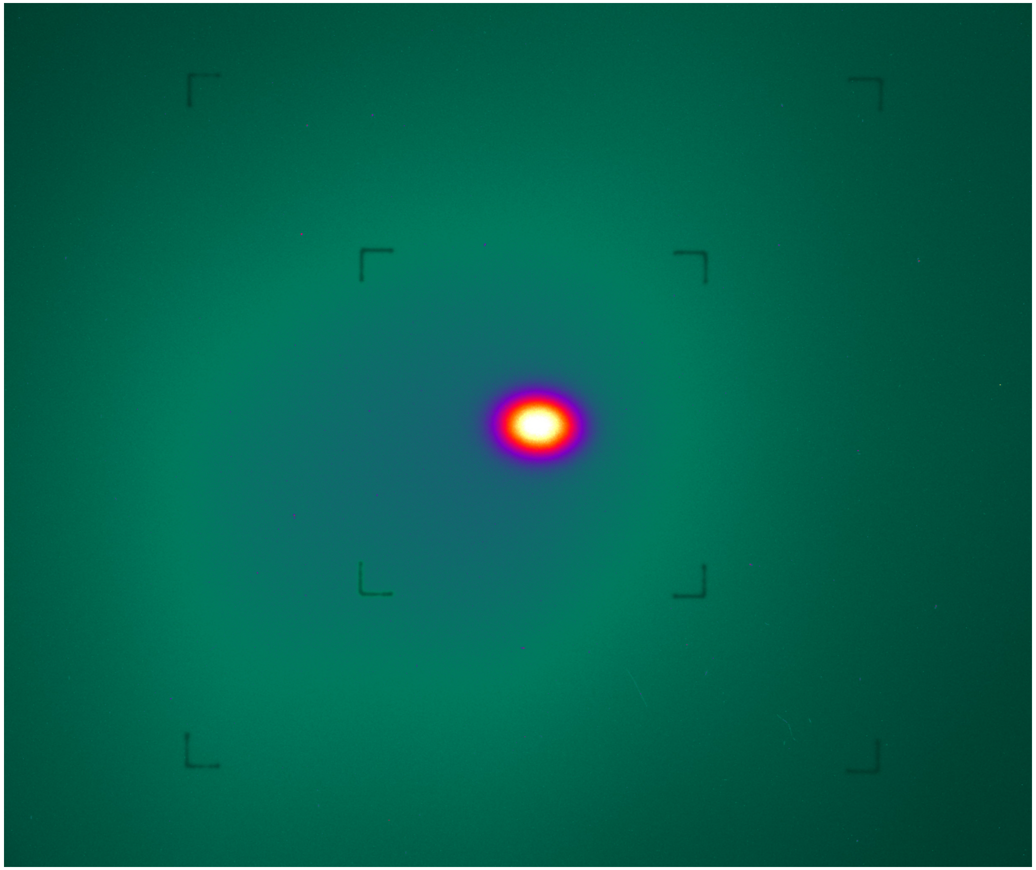
Digital beam imager provides real-time information about beam intensity and shape.

Typical beam profiles are the square 20x20 cm^2 “biology beam”.

“Physics beam” is often a round Gaussian pencil beam, with FWHM of ~1cm.

Collimation down to ~1mm is also possible.

Beam Shape



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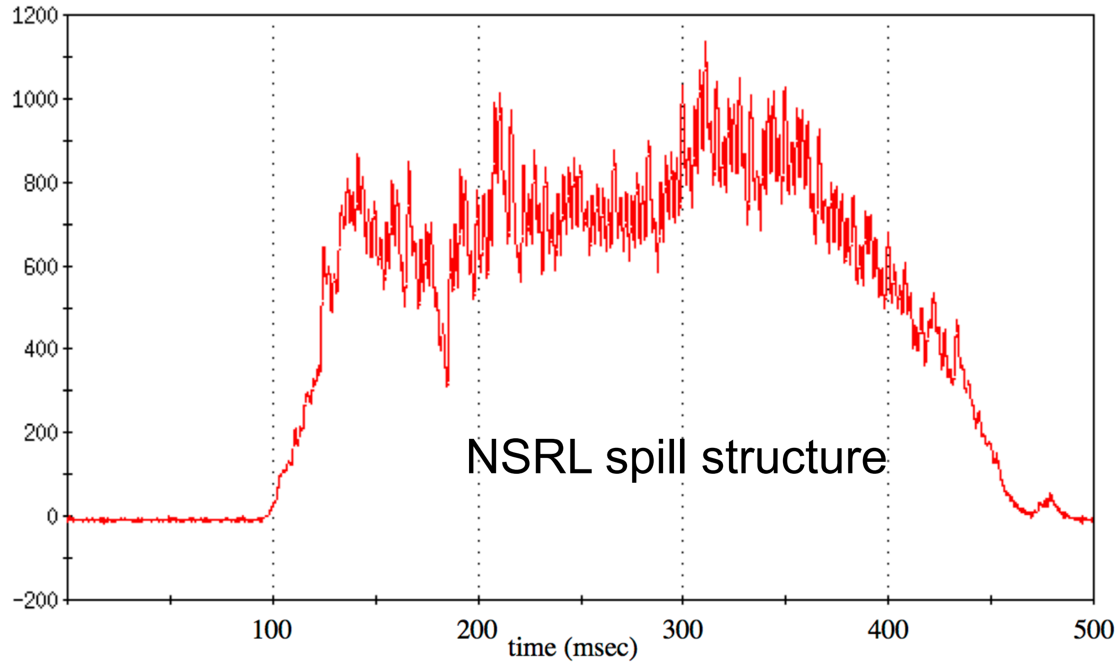
Time Structure

Beam comes from the Booster in "spills" every ~4 seconds (it was 5.2 seconds this year) in either slow or fast extraction. Normally we operate in slow spill mode, with beam delivered to the target room during a ~300 ms spill. There is some 60 Hz structure that survives filtering of the power supplies, and additional microstructure at ~2 MHz that affects the duty cycle of the data acquisition and beam diagnostics.

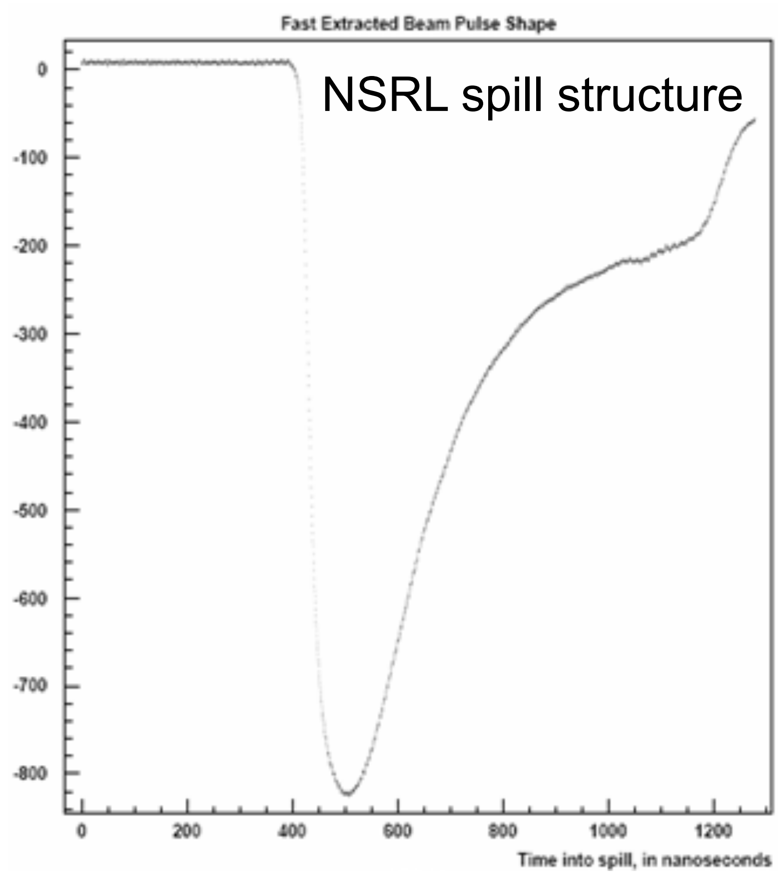
The time structure changes From spill to spill, and varies With beam energy.



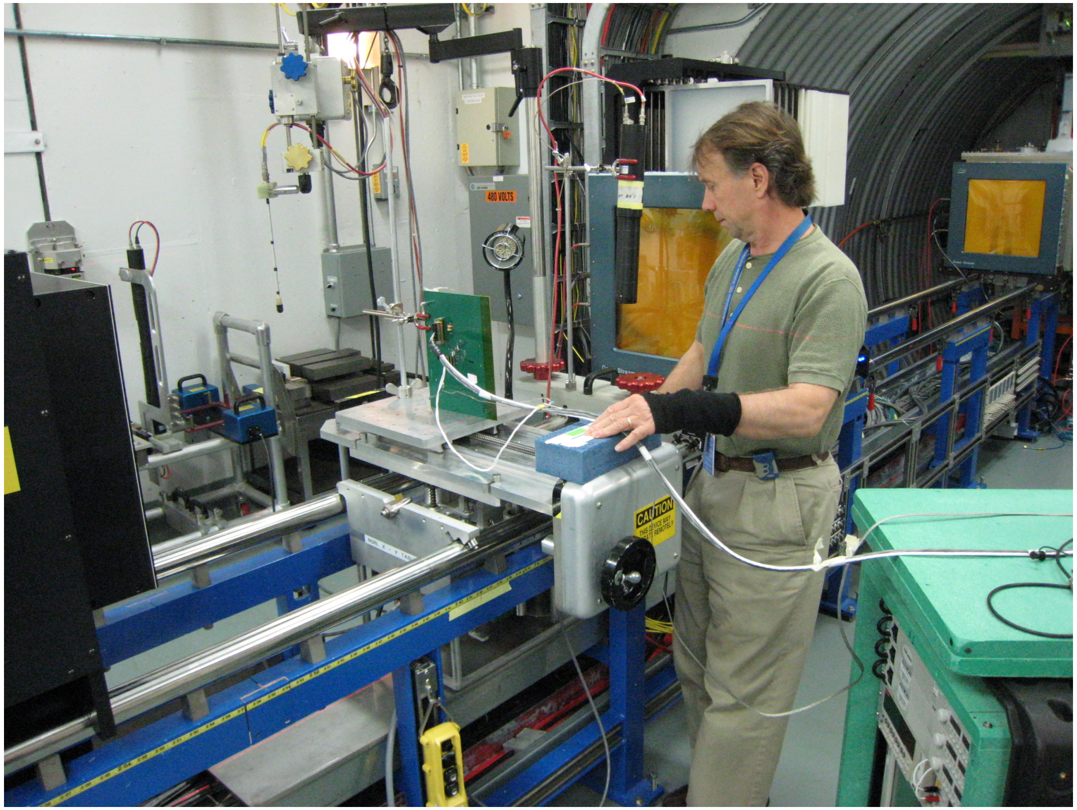
Time Structure

Fast Extracted Beam (FEB) is also possible, taking the beam out of the Booster in a single turn.   The fast spill is ~800 ns long, with most of the beam extracted in the first 400 ns.

All of the work at NSRL has been done with Slow Extracted Beam, so we do not yet have a fully developed set of tools for using FEB reliably.



Infrastructure: Target Room



- Target Room: 20’ x 20’ x 10’
- Crane coverage – ½ ton capacity.
- Laser alignment tools make finding beam center easy.
- Rails to mount targets on standard mounting plates.

Remote target control:

- Target table with X-Y stage.
- Rotational table.
- 4-ft Translation table.
- Energy degrader

Infrastructure: Access

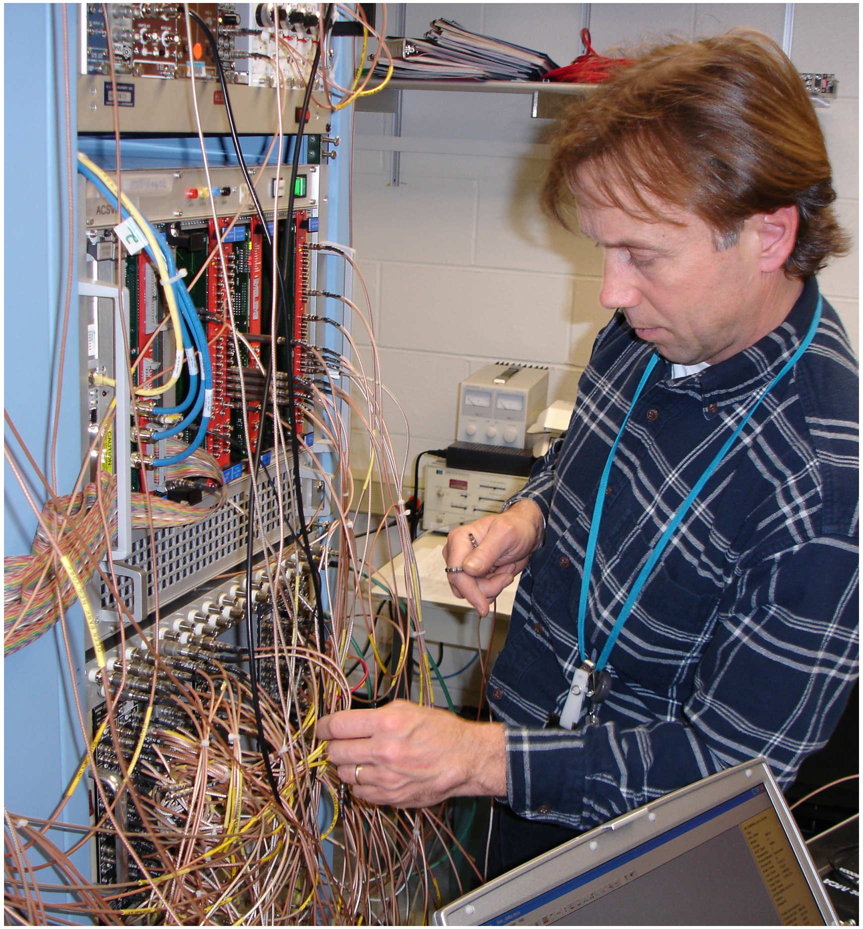
Entry doorway is 28" wide.

It can be made 72" with some work.

Labyrinth to Target Room has 4 corners and 59" width.

Access during running requires iris scan, magnetic key, and RFID tag to get past "people-reader".

Infrastructure: DAQ



VME-based data acquisition system

- Flexible, user configurable
- 2 kHz event rate
- 12- and 16-bit ADC and QDC
- 35-ps TDC
- 300 MHz scalers
- Optical Bridge

32-channel HV

64 RG-58 signal cable patch panel

32 RG-59 HV cable patch panel

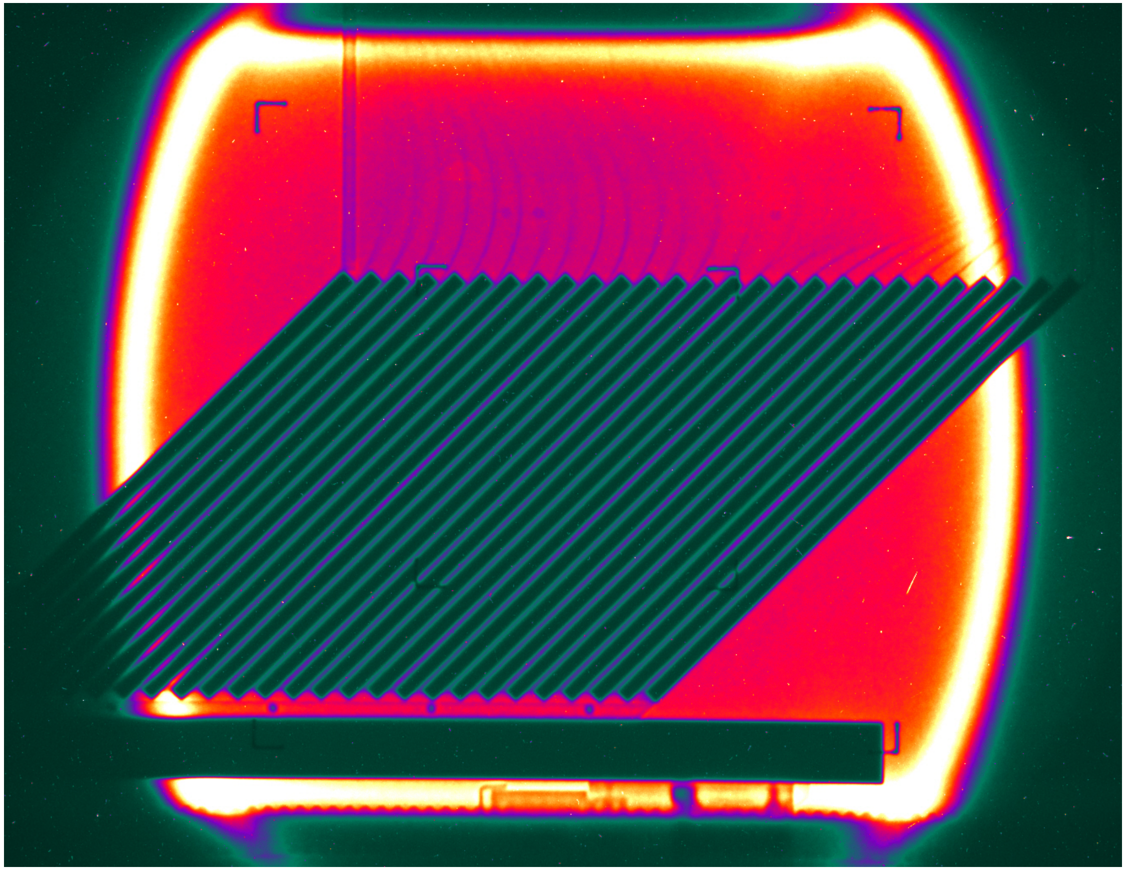
3 Tri-ax high-speed low-loss cables

3 Ethernet cables

This is where the science happens!

21 July 2014

Examples: PHENIX ZDC

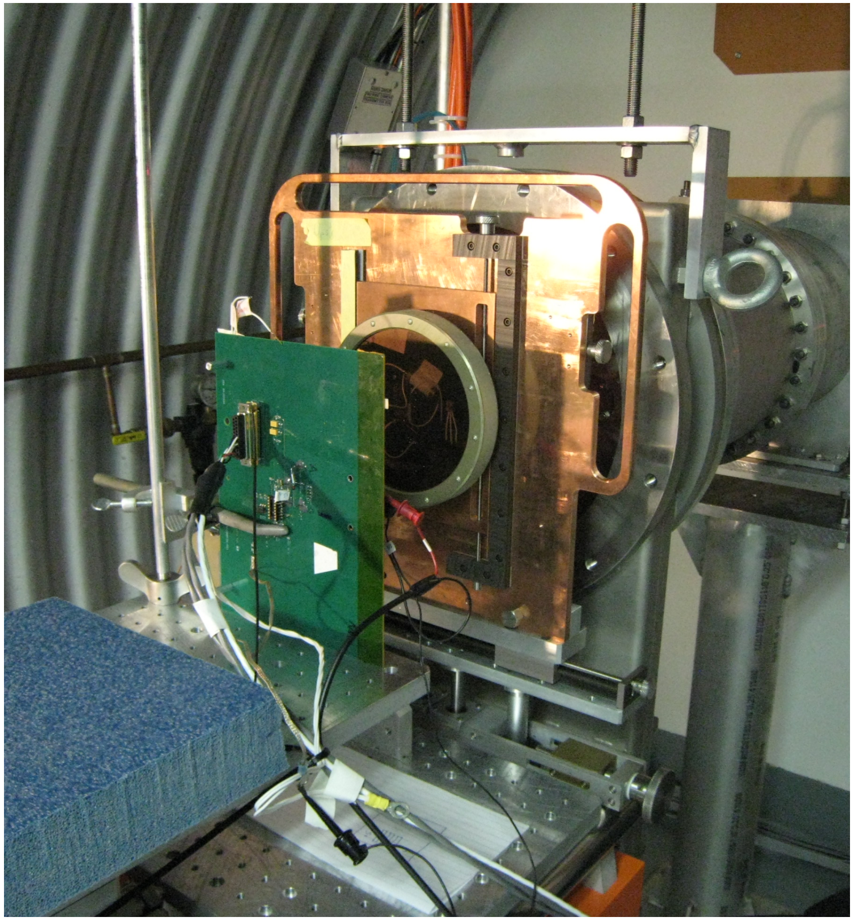


“Ferrograph” of the PHENIX ZDC module being calibrated with a 56 GeV Fe-beam (1000 MeV/n).

Data taken using the NSRL DAQ.

Entire process took less than an afternoon.

Future Directions



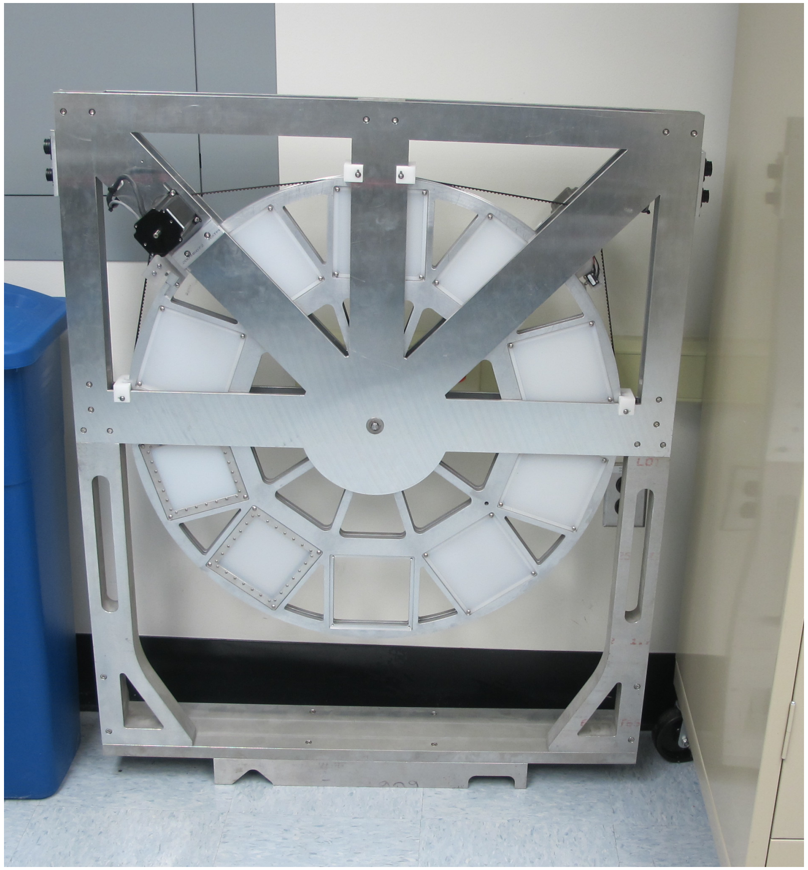
Rapid switching of ion species to allow changes on a pulse-to-pulse basis using EBIS.

NSRL is looking into increasing the maximum beam energy available for experiments. Peak rigidity could be increased by 50%, allowing for 1.5 GeV/n Fe beams, for example.

Development of a second beam line/target room is under consideration.

We have been thinking for a long time about how best to make use of neutrons in the beam…

Summary



NSRL can be a valuable tool for users interested in detector development, response testing and calibration of experimental equipment.

The most valuable tool is the skilled and enthusiastic engineering and support staff who are dedicated to making every experiment at NSRL a success.